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(54) MECHANICAL SUBCOOLING OF TRANSCRITICAL R-744 REFRIGERATION SYSTEMS WITH HEAT PUMP HEAT RECLAIM AND FLOATING HEAD PRESSURE

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F25B 1/00	(2006.01)
F25J 1/00	(2006.01)
F25B 6/04	(2006.01)
F25B 9/00	(2006.01)
F25B 40/00	(2006.01)

(52) **U.S. Cl.**
CPC ... ***F25B 1/10*** (2013.01); ***F25B 6/04*** (2013.01); ***F25B 9/008*** (2013.01); ***F25B 40/00*** (2013.01); *F25B 2400/075* (2013.01); *F25B 2400/13* (2013.01); *F25B 2400/23* (2013.01)

(58) **Field of Classification Search**
CPC F25B 6/04; F25B 9/008; F25B 40/00; F25B 1/10; F25B 2309/06
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See application file for complete search history.

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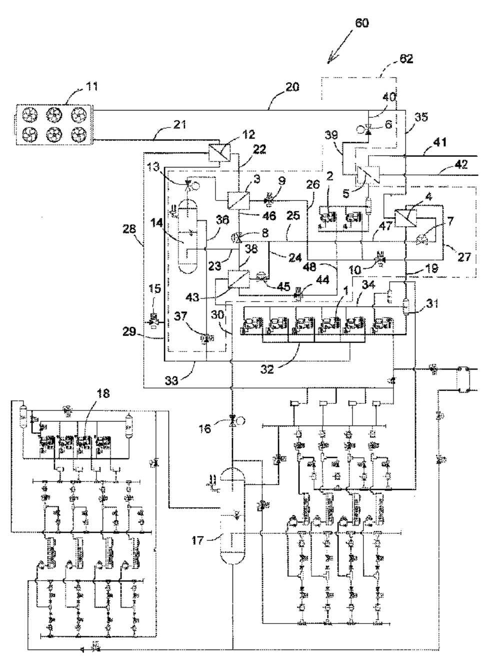
(57) **ABSTRACT**

A transcritical R-744 refrigeration system with an energy efficiency ratio of a level comparable to that of refrigeration systems using common refrigerants by mechanically subcooling of the R-744 refrigerant. Mechanical subcooling increases the refrigeration capacity without increasing the power consumption of the refrigeration system's compressors. The compressors used to provide the refrigeration capacity for the subcooling process operate at much more favorable conditions, therefore have a very high energy efficiency ratio. The result is higher refrigeration capacity and lower power consumption.

16 Claims, 2 Drawing Sheets



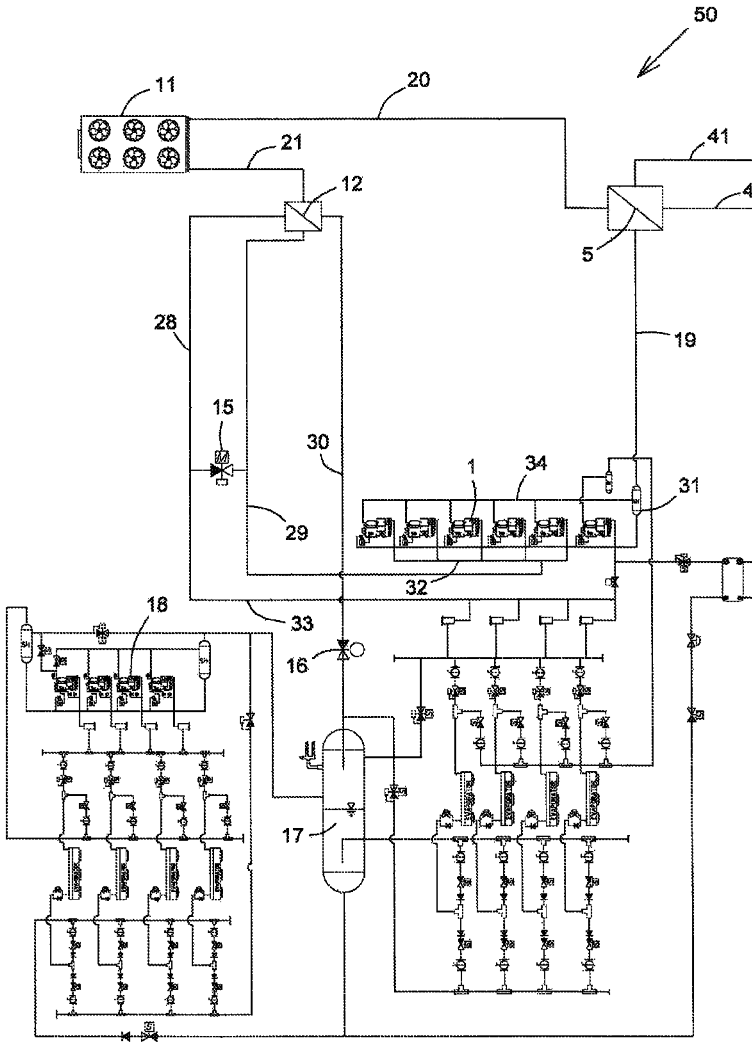


FIG.1 (PRIOR ART)

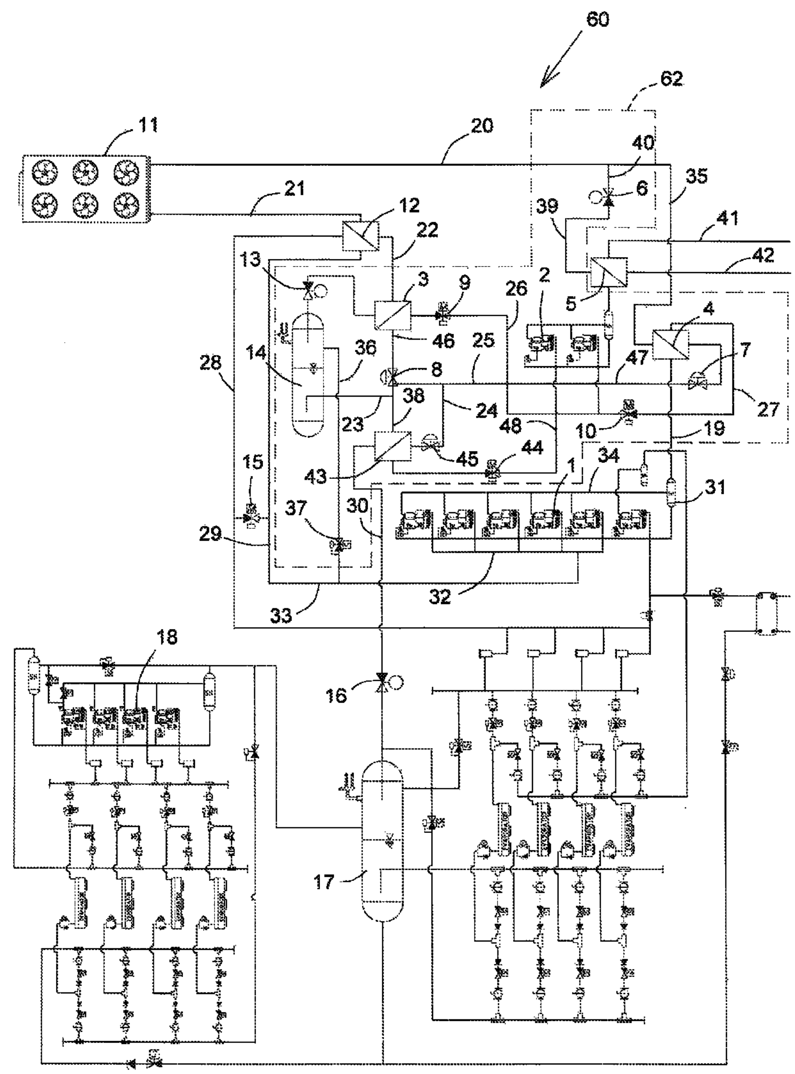

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FIG.2

MECHANICAL SUBCOOLING OF TRANSCRITICAL R-744 REFRIGERATION SYSTEMS WITH HEAT PUMP HEAT RECLAIM AND FLOATING HEAD PRESSURE

CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims the benefits of U.S. provisional patent application No. 61/602,276 filed on Feb. 23, 2012, which is herein incorporated by reference.

TECHNICAL FIELD

The present disclosure concerns refrigeration systems, and more particularly to mechanical subcooling of transcritical R-744 refrigeration systems with heat pump heat reclaim and floating head pressure.

BACKGROUND

R-744 transcritical refrigeration systems are used in supermarkets to refrigerate or to maintain in frozen state perishable products, such as foodstuff.

However, a problem with conventional R-744 transcritical refrigeration systems consists mainly of their very low energy efficiency ratio (refrigeration capacity divided by consumed power).

For example, a R-744 transcritical refrigeration system operating at 21.2° F. evaporating temperature and gas leaving the gas cooler at 98.6° F. (ambient air temperature at 90° F.) will have an energy efficiency ratio of 6.09 while a R-507 refrigeration system operating under the same conditions will have an energy efficiency ratio of 10 which is almost 50% more efficient.

Accordingly, there is a need for a system and method for improving the energy efficiency ratio of transcritical R-744 refrigeration systems.

SUMMARY

It is an object of the present disclosure to provide an improved transcritical R-744 refrigeration system with a higher energy efficiency ratio.

It is a further object of the present disclosure to provide a transcritical R-744 refrigeration system with an energy efficiency ratio (EER) of a level comparable to that of refrigeration systems using R-717, R-507, R-404a and other common refrigerants by mechanically subcooling of the R-744 refrigerant.

Accordingly, the present disclosure provides a mechanical subcooling system for use with a transcritical R-744 refrigeration system having at least one compressor for compressing R-744 vapors directed to a cooler operatively connected to a first throttling device, for reducing the pressure and temperature of the R-744 vapors to a level required for the normal operation of the R-744 refrigeration system, through a first heat exchanger, the first heat exchanger being operatively connected to the at least one compressor to provide the R-744 vapors to the at least one first compressor and to receive compressed R-744 vapors from the at least one first compressor, a by-pass valve for maintaining a required flow of R-744 vapors through the first heat exchanger, and a first receiver for receiving the R-744 vapors from the first throttling device, the first receiver being operatively connected to at least one defrost compressor, the mechanical subcooling system comprising:

- a second heat exchanger operatively connected between the at least one first compressor and the cooler;
- a third heat exchanger and a second throttling device operatively connected between the first heat exchanger and a second receiver for the separation of R-744 vapors and liquid;
- a first pressure regulating valve for feeding R-744 vapors from the second receiver to the at least one first compressor;
- at least one second compressor for mechanically subcooling of R-744 vapors leaving the cooler through the third heat exchanger or for heat reclaim through the second heat exchanger; and
- a fourth heat exchanger operatively connected between the second receiver and the at least one second compressor.

The present disclosure further provides a transcritical R-744 refrigeration system including the above-described mechanical subcooling system.

The present disclosure also provides a method for improving the energy efficiency ratio of a transcritical R-744 refrigeration system having at least one compressor for compressing R-744 vapors directed to a cooler operatively connected to a first throttling device, for reducing the pressure and temperature of the R-744 vapors to a level required for the normal operation of the R-744 refrigeration system, through a first heat exchanger, the first heat exchanger being operatively connected to the at least one compressor to provide the R-744 vapors to the at least one first compressor and to receive compressed R-744 vapors from the at least one first compressor, a by-pass valve for maintaining a required flow of R-744 vapors through the first heat exchanger, and a first receiver for receiving the R-744 vapors from the first throttling device, the first receiver being operatively connected to at least one defrost compressor, the method comprising mechanically subcooling of the R-744 vapors leaving the cooler.

BRIEF DESCRIPTION OF THE FIGURES

Embodiments of the disclosure will be described by way of examples only with reference to the accompanying drawing, in which:

FIG. **1** is a schematic diagram of a typical transcritical R-744 refrigeration system; and

FIG. **2** is a schematic diagram of the transcritical R-744 refrigeration system of FIG. **1** with mechanical subcooling in accordance with an illustrative embodiment of the present disclosure.

Similar references used in different Figures denote similar components.

DETAILED DESCRIPTION

Generally stated, the non-limitative illustrative embodiment of the present disclosure provides a transcritical R-744 refrigeration system with an energy efficiency ratio (EER) of a level comparable to that of refrigeration systems using R-717, R-507, R-404a and other common refrigerants by mechanically subcooling of the R-744 refrigerant. Mechanical subcooling increases the refrigeration capacity without increasing the power consumption of the refrigeration system's compressors. The compressors used to provide the refrigeration capacity for the subcooling process operate at much more favorable conditions, therefore have a very high energy efficiency ratio. The result is higher refrigeration capacity and lower power consumption.

R-744 Transcritical Refrigeration System

Referring to FIG. **1**, there is shown a typical R-744 transcritical refrigeration system **50**. R-744 vapors are compressed by compressors **1** and directed through conduit **34**, oil separator **31**, conduit **19**, heat exchanger **5** and conduit **20** to cooler **11**, for example a gas cooler. The heat from the compressed R-744 vapors from compressors **1** is transferred in heat exchanger **5** to, for example, a glycol circulation system through conduits **41** and **42**, to be used during the warm periods of the year for dehumidification purposes. From the cooler **11** the cooled transcritical R-744 vapors are directed through conduit **21**, heat exchanger **12** and fed through conduit **30** to throttling device **16** where its pressure and temperature are reduced to a level required for the normal operation of the refrigeration system **50** both at low and medium temperatures and then is fed to receiver **17**, which is operatively connected to defrost compressors **18**. R-744 vapors from heat exchanger **12** are directed through conduit **29** and conduit **32** to the suction of compressors **1**, which are connected through conduit **33** and conduit **28** to heat exchanger **12** where a heat transfer between R-744 vapors from the cooler **11** and the R-744 vapors from the suction of the compressors **1** takes place in order to insure stable suction temperature at a desired level. The by-pass valve **15** maintains the required flow of suction vapors through heat exchanger **12** in order to insure the required temperature of the suction vapors.

In order to increase the energy efficiency ratio (EER) of typical transcritical R-744 refrigeration systems, such as the transcritical R-744 refrigeration systems **50** in FIG. **1**, to a level comparable to the EER of refrigeration systems using R-717, R-507, R-404a and other common refrigerants, mechanical subcooling of the R-744 refrigerant leaving the cooler **11** is introduced.

R-744 Transcritical Refrigeration System with Mechanical Subcooling

Referring now to FIG. **2**, there is shown a transcritical R-744 refrigeration system with mechanical subcooling **60** in accordance with an illustrative embodiment of the present disclosure, which is basically the transcritical R-744 refrigeration system **50** of FIG. **1** to which mechanical subcooling **62** is added. The R-744 vapors compressed by compressors **1** are directed through conduit **34**, oil separator **31**, conduit **19**, heat exchanger **4**, conduit **35** and conduit **20** to cooler **11**. From the cooler **11** the cooled transcritical R-744 vapors are directed through conduit **21**, heat exchanger **12**, conduit **22**, heat exchanger **3** and throttling device **13** to receiver **14** where a separation of R-744 vapors and liquid occurs. The R-744 vapors from receiver **14** are fed through conduit **36** and pressure regulating valve **37** to conduit **33** and to conduit **32**, and to the suction of compressors **1**. The suction of compressors **1** is connected through conduit **33** and conduit **28** to heat exchanger **12** where a heat transfer between R-744 vapors from the cooler **11** and the R-744 vapors from the suction of the compressors **1** take place in order to insure stable suction temperature at a desired level. The by-pass valve **15** maintains the required flow of suction R-744 vapors through heat exchanger **12** in order to insure the required temperature of the suction vapors.

The compressors **2** are used for mechanical subcooling of the R-744 refrigerant leaving the cooler **11** through heat exchanger **3** or for heat reclaim through heat exchanger **4**. Additional subcooling is provided for R-744 refrigerant leaving the receiver **14** by means of heat exchanger **43**. The suction ports of compressors **2** are connected through motorized valves **9** and **44**, and through conduits **26** and **48** to heat exchangers **3** and **43** or through motorized valve **10** and conduit **27** to heat exchanger **4**.

When subcooling is required, valves **9** and **44** are open, and valve **10** is closed. Liquid R-744 is fed through conduits **23**, **46** and **24** to expansion valves **8** and **45**. The evaporation of the liquid R-744 in heat exchangers **3** and **43** absorbs heat from the R-744 refrigerant flowing through the other side of heat exchangers **3** and **43** (vapors in heat exchanger **3** and liquid in heat exchanger **43**), thus reducing its temperature. The liquid R-744 is then fed through conduit **30** to throttling device **16** where its pressure and temperature are reduced to a level required for normal operation of the transcritical R-744 system **60** both at low and medium temperatures, and then is fed to receiver **17**, which is operatively connected to the defrost compressors **18**.

The evaporated R-744 refrigerant from heat exchangers **3** and **43** is fed through conduits **26** and **48**, and through motorized valves **9** and **44** to the suction ports of compressors **2**. The compressed R-744 vapors from compressors **2** are fed through heat exchanger **5** and conduit **39** to throttling device **6**. From the throttling device **6** the R-744 vapors are fed through conduits **40** and **20** to cooler **11**. The heat from the compressed R-744 vapors from compressors **2** is transferred in heat exchanger **5** to, for example, a glycol circulation system through conduits **41** and **42**, and is used during the warm periods of the year for dehumidification purposes or water heating.

During colder periods of the year, where subcooling is not required, valves **8**, **9**, **44** and **45** are closed. Valves **7** and **10** are opened. Liquid R-744 is fed through conduits **23** and **47** to the expansion valve **7** and then to heat exchanger **4** where it evaporates and absorbs heat from the compressed R-744 vapors from compressors **1**, which are fed through conduit **34**, oil separator **31** and conduit **19** to heat exchanger **4**.

The heat is then, by means of compressors **2**, transferred in heat exchanger **5** to, for example, a glycol circulation system through conduits **41** and **42**, and is used for comfort heating of the premises.

Energy Efficiency

By using mechanical subcooling as disclosed above with a transcritical R-744 refrigeration system **60**, the EER may go up to, for example, about 9.27 compared to the EER of a typical transcritical R-744 refrigeration system **50**, which is about 6.09. The compressors **2** used for the mechanical subcooling have an energy efficiency ratio of about 14.00 due to their favorable operating conditions.

It is clear that the mechanical subcooling of R-744 transcritical refrigeration systems eliminates their major disadvantage of having low energy efficiency.

During the cold periods of the year, a transcritical R-744 refrigeration system with mechanical subcooling **60** can operate as a subcritical R-744 refrigeration system **50** and its energy efficiency then becomes similar to the energy efficiency of a Freon refrigeration system when the ambient air temperature is lower than about 12° C. (53.6° F.). No mechanical subcooling should be required during these periods. What is important, however, is that there is need of heat recuperation for comfort heating of the premises. The R-744 will provide heat but at a low temperature level of around 70° F., which is not appropriate for space heating.

During these periods the compressors **2** used for subcooling operate as a heat pump extracting heat from the refrigeration compressors **1** and elevate this heat to usable temperatures for space heating.

Mechanical Subcooling System

The mechanical subcooling is provided by the mechanical subcooling system **62**, which can be incorporated into existing R-744 refrigeration systems, and consists of compressors **2**, heat exchangers **3**, **4** and **43**, valves **6**, **7**, **8**, **9**, **10**, **13**, **37**, **44** and **45**, and receiver **14**.

Although the present disclosure has been described with a certain degree of particularity and by way of an illustrative embodiments and examples thereof, it is to be understood that the present disclosure is not limited to the features of the embodiments described and illustrated herein, but includes all variations and modifications within the scope and spirit of the disclosure as hereinafter claimed.

What is claimed is:

1. A mechanical subcooling system for use with a transcritical R-744 refrigeration system having at least one compressor for compressing R-744 vapors directed to a cooler operatively connected to a first throttling device, for reducing the pressure and temperature of the R-744 vapors to a level required for the normal operation of the R-744 refrigeration system, through a first heat exchanger, the first heat exchanger being operatively connected to the at least one compressor to provide the R-744 vapors to the at least one first compressor and to receive compressed R-744 vapors from the at least one first compressor, a by-pass valve for maintaining a required flow of R-744 vapors through the first heat exchanger, and a first receiver for receiving the R-744 vapors from the first throttling device, the first receiver being operatively connected to at least one defrost compressor, the mechanical subcooling system comprising:
- a second heat exchanger operatively connected between the at least one first compressor and the cooler;
- a third heat exchanger and a second throttling device operatively connected between the first heat exchanger and a second receiver for the separation of R-744 vapors and liquid;
- a first pressure regulating valve for feeding R-744 vapors from the second receiver to the at least one first compressor;
- at least one second compressor for mechanically subcooling of R-744 vapors leaving the cooler through the third heat exchanger or for heat reclaim through the second heat exchanger; and
- a fourth heat exchanger operatively connected between the second receiver and the at least one second compressor.

2. The mechanical subcooling system of claim 1, further comprising a third throttling device operatively connected between the at least one second compressor and the cooler.

3. The mechanical subcooling system of claim 1, the transcritical R-744 refrigeration system further including a fifth heat exchanger operatively connected between the at least one second compressor and the cooler for transferring heat to a circulation system to be used during warm periods for dehumidification purposes.

4. The mechanical subcooling system of claim 3, further comprising a third throttling device operatively connected between the fifth heat exchanger and the cooler.

5. The mechanical subcooling system of claim 1, further comprising:
- a first motorized valve operatively connected between the third heat exchanger and the at least one second compressor;
- a second motorized valve operatively connected between the fourth heat exchanger and the at least one second compressor; and
- a third motorized valve operatively connected between the second heat exchanger and the at least one second compressor.

6. The mechanical subcooling system of claim 5, wherein when subcooling is required, the first and the second motorized valves are open, and the third motorized valve is closed.

7. The mechanical subcooling system of claim 5, further comprising:
- a first expansion valve operatively connected between the second receiver and the third heat exchanger;
- a second expansion valve operatively connected between the second receiver and the fourth heat exchanger; and
- a third expansion valve operatively connected between the second receiver and the second heat exchanger.

8. The mechanical subcooling system of claim 7, wherein when subcooling is not required, the first and the second expansion valve, and the first and the second motorized valves are closed, and the third expansion valve and the third motorized valve are opened.

9. A transcritical R-744 refrigeration system having at least one first compressor for compressing R-744 vapors directed to a cooler operatively connected to a first throttling device, for reducing the pressure and temperature of the R-744 vapors to a level required for the normal operation of the R-744 refrigeration system, through a first heat exchanger, the first heat exchanger being operatively connected to the at least one first compressor to provide the R-744 vapors to the at least one first compressor and to receive compressed R-744 vapors from the at least one first compressor, a by-pass valve for maintaining a required flow of R-744 vapors through the first heat exchanger, a first receiver for receiving the R-744 vapors from the first throttling device, the first receiver being operatively connected to at least one defrost compressor, and a mechanical subcooling system as claimed in claim 1.

10. A transcritical R-744 refrigeration system having at least one first compressor for compressing R-744 vapors directed to a cooler operatively connected to a first throttling device, for reducing the pressure and temperature of the R-744 vapors to a level required for the normal operation of the R-744 refrigeration system, through a first heat exchanger, the first heat exchanger being operatively connected to the at least one first compressor to provide the R-744 vapors to the at least one first compressor and to receive compressed R-744 vapors from the at least one first compressor, a by-pass valve for maintaining a required flow of R-744 vapors through the first heat exchanger, a first receiver for receiving the R-744 vapors from the first throttling device, the first receiver being operatively connected to at least one defrost compressor, and a mechanical subcooling system as claimed in claim 2.

11. A transcritical R-744 refrigeration system having at least one first compressor for compressing R-744 vapors directed to a cooler operatively connected to a first throttling device, for reducing the pressure and temperature of the R-744 vapors to a level required for the normal operation of the R-744 refrigeration system, through a first heat exchanger, the first heat exchanger being operatively connected to the at least one first compressor to provide the R-744 vapors to the at least one first compressor and to receive compressed R-744 vapors from the at least one first compressor, a by-pass valve for maintaining a required flow of R-744 vapors through the first heat exchanger, a first receiver for receiving the R-744 vapors from the first throttling device, the first receiver being operatively connected to at least one defrost compressor, and a mechanical subcooling system as claimed in claim 3.

12. A transcritical R-744 refrigeration system having at least one first compressor for compressing R-744 vapors directed to a cooler operatively connected to a first throttling device, for reducing the pressure and temperature of the R-744 vapors to a level required for the normal operation of the R-744 refrigeration system, through a first heat exchanger, the first heat exchanger being operatively connected to the at least one first compressor to provide the R-744 vapors to the at least one first compressor and to receive compressed R-744 vapors from the at least one first compressor, a by-pass valve for maintaining a required flow of R-744

vapors through the first heat exchanger, a first receiver for receiving the R-744 vapors from the first throttling device, the first receiver being operatively connected to at least one defrost compressor, and a mechanical subcooling system as claimed in claim **4**.

13. A transcritical R-744 refrigeration system having at least one first compressor for compressing R-744 vapors directed to a cooler operatively connected to a first throttling device, for reducing the pressure and temperature of the R-744 vapors to a level required for the normal operation of the R-744 refrigeration system, through a first heat exchanger, the first heat exchanger being operatively connected to the at least one first compressor to provide the R-744 vapors to the at least one first compressor and to receive compressed R-744 vapors from the at least one first compressor, a by-pass valve for maintaining a required flow of R-744 vapors through the first heat exchanger, a first receiver for receiving the R-744 vapors from the first throttling device, the first receiver being operatively connected to at least one defrost compressor, and a mechanical subcooling system as claimed in claim **5**.

14. A transcritical R-744 refrigeration system having at least one first compressor for compressing R-744 vapors directed to a cooler operatively connected to a first throttling device, for reducing the pressure and temperature of the R-744 vapors to a level required for the normal operation of the R-744 refrigeration system, through a first heat exchanger, the first heat exchanger being operatively connected to the at least one first compressor to provide the R-744 vapors to the at least one first compressor and to receive compressed R-744 vapors from the at least one first compressor, a by-pass valve for maintaining a required flow of R-744 vapors through the first heat exchanger, a first receiver for receiving the R-744 vapors from the first throttling device, the first receiver being operatively connected to at least one defrost compressor, and a mechanical subcooling system as claimed in claim **6**.

15. A transcritical R-744 refrigeration system having at least one first compressor for compressing R-744 vapors directed to a cooler operatively connected to a first throttling device, for reducing the pressure and temperature of the R-744 vapors to a level required for the normal operation of the R-744 refrigeration system, through a first heat exchanger, the first heat exchanger being operatively connected to the at least one first compressor to provide the R-744 vapors to the at least one first compressor and to receive compressed R-744 vapors from the at least one first compressor, a by-pass valve for maintaining a required flow of R-744 vapors through the first heat exchanger, a first receiver for receiving the R-744 vapors from the first throttling device, the first receiver being operatively connected to at least one defrost compressor, and a mechanical subcooling system as claimed in claim **7**.

16. A transcritical R-744 refrigeration system having at least one first compressor for compressing R-744 vapors directed to a cooler operatively connected to a first throttling device, for reducing the pressure and temperature of the R-744 vapors to a level required for the normal operation of the R-744 refrigeration system, through a first heat exchanger, the first heat exchanger being operatively connected to the at least one first compressor to provide the R-744 vapors to the at least one first compressor and to receive compressed R-744 vapors from the at least one first compressor, a by-pass valve for maintaining a required flow of R-744 vapors through the first heat exchanger, a first receiver for receiving the R-744 vapors from the first throttling device, the first receiver being operatively connected to at least one defrost compressor, and a mechanical subcooling system as claimed in claim **8**.

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